BELLCOMM, INC.

SUBJECT: Behavioral Aspects for Consideration in Long Duration Space Flights
Case 233

DATE: March 16, 1967

FROM: D. B. Hoffman

ABSTRACT

The physical and interpersonal factors affecting crew performance during long duration missions are reviewed with an attempt to clarify the present state of knowledge, and to criticize the available literature. An effort is made to present guidelines for consideration in the planning for the hardware and missions, and to indicate potential problem areas and those in which further research is needed.

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(NASA-CR-153721) BEHAVIORAL ASPECTS FOR CONSIDERATION IN LONG DURATION SPACE FLIGHTS (Bellcomm, Inc.) 20 p

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MEMORANDUM FOR FILE

In contrast to the short one and two-man space flights, planning of systems and operations for long duration, multi-man missions must seriously consider the socio-psychological health of the crew. Studies of simulated situations and information from actual events were used in the following review. When simulation was realistic, the results were similar to those from actual experiences (Ref. 1).

Behavioral changes were observed in these studies, including impairment of thinking, childish emotional responses disturbances of visual perception, fatigue, boredom, restlessness, depression, irrationality, irritability, insomnia, anxiety, hallucinations, interpersonal hostility, loss of crew morale, and loss of group cohesiveness (Ref. 1,2,3,4,5). The severity of these manifestations depends strongly on physical and interpersonal factors which are subject to control in systems design. This memorandum considers first the physical factors and then the interpersonal or social factors.

A. PHYSICAL FACTORS

Four aspects of the "physical environment" have been considered important. These are: isolation, the "separation of the individual from his natural environment and the disruption of his accustomed patterns"; confinement, the restraint or restriction of movement within fixed boundaries; habitability, the fitness of the environment for occupation as perceived by the individual; and work-rest scheduling.

1. Isolation

The relevant literature on isolation studies has been extensively reviewed in Reference 1. Unfortunately, many of the investigations were concerned with the isolation of only one individual, sometimes under bizarre conditions (Ref. 6). In addition, many of the experiments were concerned with sensory deprivation rather than isolation alone, and involved some degree of confinement, often severe. Thus, the interpretation of the isolation experiments is complicated by the variability in conditions of exposure (Ref. 1,2,3,4,5).

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In all of the single man isolation studies performance decrements occurred (Ref. 1,5,7,8). Hallucinations were even observed when isolation was compounded with sensory deprivation. These occurrences can be avoided when good sensory validation is present or when communications links are provided to the outside. They rarely occur when two subjects are confined together and never with three or more (Ref. 1,9).

Milder decrements such as boredom, anxiety or depression were also observed. When tasks were scheduled in simulation studies, such effects of isolation were diminished (Ref. 1), but the amount of adaptation has been found to be subject to individual variation (Ref. 10). Selection of personnel more capable of enduring isolation has been suggested if adequate criteria can be established (Ref. 11). In addition, training for isolation may be possible, using films showing potential psychological difficulties and suggesting preventive or corrective measures.

Although a significant variation in response has been reported, possibly due to the many differences endemic in the experiments, one may conclude from the literature that the effects of isolation can be minimized if several subjects are isolated together, if sensory underload and overload are avoided, if communications links are provided with the outside, and if the crew is provided with meaningful tasks.

2. Confinement

Short term confinement in space has caused no apparent psychological problems (Ref. 12, 13). A large body of literature concerning confinement studies has been reviewed extensively in References 1 and 14 and indicates, however, that potential problems may arise under prolonged confinement. The results of simulated studies and authentic events such as Arctic expeditions, submarine missions, bomber missions, etc., reveal the importance of the available volume per man as an index of confinement. The severity of psychological problems and performance decrements occurring during confinement were increased with increase in mission duration or with decreases in the available volume per man. If the crew size was increased but the volume per man maintained constant, performance could be kept from deteriorating as the mission duration increased. Finally, at increased volume per man, mission duration could be increased without performance decrements.

A theoretical attempt based on anthropometrics to detail the ideal minimum volume per man as a function of mission duration was attempted by Davenport et al (Ref. 14). The resulting increase in the required volume per man as both mission duration and crew size increase (Figure 1) is expected to arise from the proliferation of tasks, the desirability for specific task areas, and the need for private space. This study would indicate that a five man crew would need a minima of 140 ft^3/man and 175 ft^3/man for 60 and 400 day missions respectively.

Other suggestions of the minimum required volume/man for long duration missions have been reported. Fedderson (Ref. 15) suggested sleep/rest station volumes of at least 300 ft^3/man and separate work areas of as yet undetermined size. Fraser (Ref. 1,9) and Jones et al (Ref. 16) have derived thresholds of acceptable volume/man through a subjective evaluation of simulation and field performance. These results disagree with those reported by Davenport's group, indicating that the minimum required volume/man may approach a constant beyond 30 to 60 days (Figures 2 and 3). Submarine missions of long duration have been completed with no crew psychological problems (Ref. 1,2). In these cases the available volume was about 600 ft^3 per man yielding one estimate of the required volume for acceptable performance.

One may conclude that the qualitative estimates presently available would indicate a required minimum volume of 150-200 ft^3/man and an acceptable performance volume of 600 ft^3/man for long duration missions. It should be noted that the S-IVB spent stage contains 12,000 ft^3. On this basis it could accomodate a 20 man crew.

3. <u>Habitability</u>

Habitability factors can obviously influence the crew morale and are increasingly important as the mission durations are increased. Optimization of such factors as plentiful water for showers, an abundance of high quality food, juke box music, reading materials and the separation of living and working quarters (Ref. 2,14,17) was at least partly responsible for the high morale and good emotional health of the crews of the Submarine Nautilus (Ref. 2) and Sealab II (Ref. 17). The lighter suits worn by the Gemini VII astronauts have been suggested as an important factor in the maintenance of their psychological and physiological health (Ref. 13). This crew may also have benefitted from periods during which they were unsuited.

4. <u>Work-Rest Scheduling</u>

The literature on work-rest scheduling has been reviewed in Reference 4. Experimental objectives have been to maximize the time available for work while avoiding work decrements and health deterioration. Variables included the work period, rest period, and sleep period durations and sequencing, and the cycle length.

In the experiments the maximum efficiency obtained without performance or health decrements was 50% working time using a 4/4 work-rest schedule for a period of 30 days. A 4/2 work-rest schedule yielding 66% working time was effective without decrements for limited duration.

The length of effective duty period depends also upon the nature of the task (Ref. 4, 18). Work-rest scheduling experiments have indicated that routine tasks are tolerable for less than 2 hours, while active tasks demanding a high degree of participation with a variety of demands have been performed for periods of up to ten hours duration without performance decrement. In general, the more monotonous the task the shorter the duty period must be.

Man's biological 24 hour periodicities, referred to as circadian rhythms (heart rate, respiration rate, vital capacity, body temperature, sensitivity to toxic agents, etc.) also influence the work-rest scheduling. Performance follows a circadian periodicity, but the decrement occurring under unusual work-rest cycles has been found to vary with the individual and can be minimized by appropriate training. Satisfactory performance has been maintained up to 30 days on a 4/4 work-rest schedule, even though the majority of circadian rhythms were still entrained to a 24 hour periodicity and no additional sleep periods were allowed.

Under unusual schedules the depth of sleep has been less than normal. In the Gemini missions little and poor quality sleep was obtained by the crews except on the GT VII flight in which both crew men slept simultaneously, and the sleeping period corresponded to that of the launch site (Ref. 13). The Sealab crews also slept poorly, but this may have been due to physiological stress caused by the high pressure and the unusual atmosphere (Ref. 17,19). In work-rest experiments, sleep periods of less than 2 hours were unacceptable.

The work-rest cycle chosen will be adapted to the mission type. For example, duties in an orbiting lab would be totally different than those on interplanetary missions. In the latter especially, the cycle will have to be flexible to meet the varying demands of the mission profile. Relaxed low efficiency cycles may suffice for interplanetary travel, but high efficiency-high demand schedules would be necessary to maximize use of the crew during encounter.

The available literature indicates that for the long term space flight, a 4/4 work-rest cycle combined with a six to eight hour sleep session occurring at the same time each day, may be suggested as a guide to optimize performance when both psychological and physiological aspects are considered. Such a schedule would favor crew health, and would permit changes in the cycles to accomodate periods of high work load. Whatever the work cycle chosen, it would seem wise at the present state of knowledge to adhere to a 24 hour periodicity.

B. INTERPERSONAL FACTORS

Although problems with motivation, hostility, group cohesiveness, and group effectiveness were not observed in the one and two man short duration missions (Ref. 13), these interpersonal areas must be considered as possible problem areas for long duration multi-man missions. In addition, interpersonal factors affecting the crew size and structure for such missions should be elucidated.

1. Hostility

Hostility has appeared in most multi-man missions and simulation situations. It generally increased with time with some anticipatory decrease observed just prior to the scheduled end of the mission during which hostility declined and cohesiveness increased (Ref. 1,20,21,22). In simulation experiments, hostility was sometimes displaced and directed towards the monitors (Ref. 1,19,23), not always the other crew members. The monitors were also considered to be omnipotent and omniscient, a relationship which could be useful during an emergency or in periods of great stress (Ref. 24).

In one experiment sociologically matched and unmatched isolated and confined pairs were compared with similar controls. As expected, the isolated dyads developed much higher levels of interpersonal hostility than non-isolated pairs, and unmatched pairs exhibited a higher degree of stress than the matched ones. Hostility was great enough to cause premature mission termination in several cases (Ref. 25). Thus, although hostility has not been a significant factor in actual missions, experiments indicate that hostility related problems could arise in future missions where interpersonal factors may be of greater importance.

2. Group Cohesiveness

Group cohesiveness was found to deteriorate, even under highly habitable situations with realistic mission simulations and psychologically screened crews (Ref. 1,3,6). Selective subgroupings were observed to occur rapidly and along lines of similar occupation. However, in none of these crews were cohesive decrements serious enough to interfere with the performance of tasks necessary for the success of the simulated mission.

Information obtained from polar expeditions, submarine cruises, and service on remote radar sites, indicates that general sociological stress is present in such groups. For instance, the work role is magnified in importance and all prerogatives jealously guarded. Hostility accompanied by a general drop in group cohesiveness is also evident. In general, these problems are less evident in large crews. The importance of careful planning, group discipline, and intelligent leadership has been demonstrated by a study (Ref. 2) dealing with psychological aspects of the crew of the Submarine Nautilus, during the first subpolar journey. These men were subjected to isolation, confinement, hazardous conditions, and participation in an historic event. No major emotional problems were encountered. Some of the stress-reducing factors present were the degree of habitability offered by the ship, the clear definition of roles, and confidence in the technical capabilities of the crew, in the competence of the officers, in the emergency procedures, and the belief in mission objectives (Ref. 2,26).

3. Motivation

Crew motivation is a particularly important factor. After reviewing the available literature on confinement, Fraser concludes that "Of the personal variables which influence the response to confinement, there is little doubt that motivation, backed by experience, is one of the most significant factors in maintaining tolerance to confinement." (Ref. 1). High crew motivation may also have been an important factor contributing to the success of the GT VII mission where the volume per man and habitability were quite low.

4. Crew Size, and structure

Two aspects of crew structure which have received little attention are the crew size and the crew leadership structure.

a. Crew size A partial list of factors affecting the crew size would include the payload weight, the available volume, the life support capability, the availability of food, the task requirements, work-rest cycles, geometric factors in interacting groups (Ref. 27), interpersonal needs, and group stability. Most of these factors would tend to reduce the crew size. However, stress is also caused by limiting both the range of social roles available to the individual and the availability of interpersonal interaction by reducing the number of individuals to which each crew man is exposed. While the engineering constraints can be used to yield a number for an adequate crew, the interpersonal-social requirements which must also be satisfied are not easily quantifiable. In addition, few size constraints for optimum group effectiveness have been noted, and these have only stated that the larger the group, the fewer the problems.

A one man crew would be susceptible to problems of isolation and sensory deprivation coupled with periods of sensory overload due to task requirements. Two man crews have been found to develop considerable mutual irritation after long durations of close proximity. Three man crews are believed to be even more unstable, because of the danger of two reinforcing each other and allying against the third. With larger groups cliquing becomes a possibility and can reduce the communications and effectiveness of the crew. Methods of clique identification have been developed (Ref. 23,29,30). However, these post-facto methods cannot yield an a priori judgement as to the size a general crew must reach before cliquing occurs, and do not identify remedial methods to cope with the detected fragmentation.

At this time, an optimum crew size cannot be specified without regard for the mission or at least the available volume. However, as an example based on acceptable performance volumes and interpersonal considerations, crew size should vary between 4 and 20 men in the case of S-IVB spent stage utilization.

b. Crew Structure In the anecdotal literature, group structure has generally been predetermined, and the leadership has been able to maintain its authority. However, in a space mission away from Earth-based higher authority, the predetermined group structure may have to be strongly reinforced in order to avoid role rearrangements, group breakdown, or status levelling. It has been suggested that groups tend to restructure themselves, especially in the face of intergroup competition for a prize (Ref. 31). The leadership will have to maintain group discipline at all times and impose authority during crisis situations. Leaders without these qualifications are usually replaced by the group (Ref. 32).

In the underwater system Sealab II, the crew was selected from experienced divers, all highly dedicated to their careers. After the completion of a 45-day mission the aquanauts ranked the desired characteristics of the ideal crew member. Experience, cooperativeness and technical competence were considered important, while the more interpersonal factors were ranked lower by the crew. Leadership characteristics chosen by the crew were age and maturity.

Studies of bomber crews revealed that crewmen rated each other in terms of achievements and their officers in terms of effectiveness. Crew morale and agreement was higher in crews with considerable experience in flying together (Ref. 5).

One may conclude that, in general, personal competence and experience are more important than social factors for effective group performance under demanding situations.

C. EVALUATION OF THE LITERATURE

Data from simulation experiments and field experiences have been cited above. While these all have common aspects, such as isolation, confinement, small group interactions, etc., they obivously differ from long duration space flight missions in several ways. Therefore, in order to derive recommendations applicable to the space program, these experiments must be ranked by their relevance to space flight.

Such a ranking was attempted by Sells (Ref. 24). A comparison was made for eleven experiment systems based on seven primary characteristics (Figure 4). Submarine crews received the highest ranking, followed by exploration parties and expeditions, naval ship crews, bomber crews and remote duty crews. The analysis suffered several shortcomings. First, the primary and secondary characteristics were not ranked by importance. Secondly, since some categories had more secondary characteristics than others, an effective accidental ranking of the secondary characteristics occurred. For example, personnel composition was ranked evenly with technology, while motivation was considered less important than aviation tradition. This type of analysis also failed to account adequately for such tremendous differences as the available volume per man in a submarine (600 ft^3/man) and a space ship (100 ft^3/man), and the considerable differences in habitability of a submarine and a POW camp. Thus, the ranking in Figure 5 may be misleading, and the necessity of a re-evaluation is suggested.

An underwater system, Sealab II (Ref. 17,18), could be considered an ideal comparative system for long duration space missions inasmuch as a small group was isolated and confined on a real mission and confronted with psychological and physiological stress. However, the volume per man was about 350 ft^3, greater than that expected inside a spacecraft, and the habitability much more favorable than could be expected on a long space mission (Ref. 17,19). The comparison would be much more realistic if a vehicle of large volume (such as the S-IVB spent stage) were to be used. In addition, the extensive daily extravehicular activity of the aquanauts and the presence of normal gravity during intravehicular operations cannot be matched in a space mission.

The large majority of simulation studies are very dissimilar to the long term space mission. In addition, such studies usually involved a one-man crew. As seen in Figure 5, the region of probable greatest interest for long term manned missions (from 4 to 20 crew members) is precisely the most unexplored region. Furthermore, as seen in Figure 6, the mission durations were almost always short, the great majority being less than ten days. One might ask what fraction of the flight must be simulated in order to be sure of the correctness of extrapolation. While this is unknown, studies have revealed problems in short duration simulations which may be aggravated in longer missions.

D. CONCLUSIONS

Ground based and anectodal studies indicate that deviation from normal responses are possible under stressful situations. As indicated previously, these experiments varied greatly in physical environment and often failed to account adequately for important factors such as motivation and response present in the real situation. The following conclusions have been reached through interpretation of the available literature in light of its admitted limitations.

1. Physical

The unusual demands of long duration space flight emphasize the importance of overcoming problems which could arise from the isolation and confinement of the crew. The effects of isolation can be relieved through adequate communications with Earth and possibly special efforts such as graduate-level lectures. Tasks should be programmed to provide adequate and meaningful work for the entire crew, and to avoid stress arising from boredom or monotony. Moreover, the crew will probably never be isolated in the strict sense studied in the laboratory.

The confinement of the crew will have both physiological and psychological effects. These effects can be minimized by programming physical exercise, allowing the crew to live unsuited at least part of the time, and keeping the volume/man as large as possible.

In all experiments in which the volume per man was ample, the problems arising from confinement were mostly eliminated, making the volume/man one of the most serious considerations in the design of the space vehicle and the size of the crew. In general, the longer the mission duration, the larger the volume per man required. Several investigators have indicated that for missions exceeding thirty days duration, a minimum volume of 150 - 200 ft^3/man is necessary for the psychological health of the crew. However, satisfactory performance in submarine missions indicates that a more realistic requirement might be 600 ft^3 per man.

The effects of confinement and restricted social interaction can also be decreased by optimizing the habitability of the ship. In experiences in which the crew performed optimally, the response was partly attributable to maximization of habitability through appropriate recreation, private areas, separate sleeping and working areas, adequate work-rest cycles, abundant high quality food, and adequate shower facilities. Such factors should be used as guidelines in the planning of long duration space mission.

Activity scheduling and work-rest cycles will vary at different times in the mission. The planning must consider the nature of the job, a shorter work period being necessary for monotonous tasks. An experimental work schedule built around a 4 hour work period utilized 50% of the available time for tasks with no performance decrement observed up to thirty days in simulation and could prove useful during periods of high demand. It may be important to use a less demanding schedule for very long missions. In addition, a six to eight hour sleep period preferably occurring at the same time each day plus the preservation of a 24 hour periodicity could eliminate possible problems arising from changing man's circadian rhythm patterns.

2. <u>Interpersonal</u>

Some interpersonal problems occurred with multi-man crews. Hostility, irritability, and anxiety were present during long exposures or long simulations. Group cohesion suffered some breakdown. Confidence in the crew, the leadership, the hardware, the ship, and emergency procedures had a general ameliorative effect. The work role was very important and the clear definition of work roles including avoidance of job overlap could prevent antagonisms arising from jealousy. Even when hostility was present, the importance and possibly the novelty of the missions influenced the crew to perform successfully indicating that motivation is a factor of highest importance.

Particularly interesting were the ranking of the important individual qualifications by WWII bomber crews and the aquanauts from Sealab II. Generally, personal experience and competence of the crew men, and command ability and maturity of the leadership were considered far more important than psychological or sociological attributes. Of importance is the high group cohesiveness resulting from experience gained working as a team. These results emphasize the need for long term simulation or a several month mission to "season" the crew. Further, to avoid work role problems, and to acknowledge the importance of leadership, the mission commanders may be chosen from pilots as is now the practice. However, as indicated in Reference 25 the remainder of the crew should be selected on a different basis with more emphasis on experience, technical skills, and social qualities. Any crew member must be able to work equally well in isolation or as a member of the team. The crew leader must be effective and mature and able to maintain discipline when he is inaccessible to communication or in the face of crisis.

The crew size is limited by engineering, task allocation and sociological constraints, none of which have been clearly defined but will be mission specific. A minimum crew should be larger than three members but no optimal size can be stated. The maximum size may be set by consideration of the volume per man.

Personal motivation may be one of the most important qualities of a crew man. In long duration missions the remoteness and uncertainty of the payoff require high crew motivation for satisfactory performance.

A number of comparative systems were compared in searching for similarities with the long duration space mission. Submarine missions appeared to be the most similar while disaster situations were the least. However, the analysis is somewhat questionable, since factors of greatly differing importance were ranked equally.

Simulation studies also have shortcomings. Most of the work has been performed with too small a crew and too short a simulation period. Thus, applicability of results obtained from both comparative systems and simulated situations is questionable and there is need for further studies, combined with missions of increasing duration.

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Attachment
Figures 1 through 6

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(see next page)

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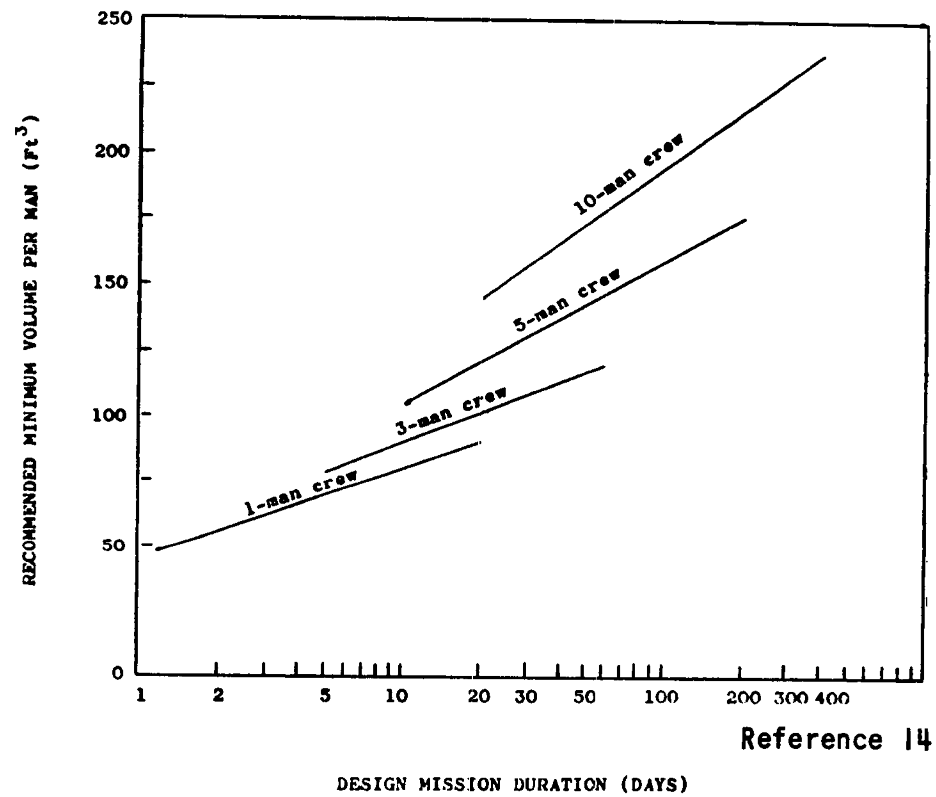
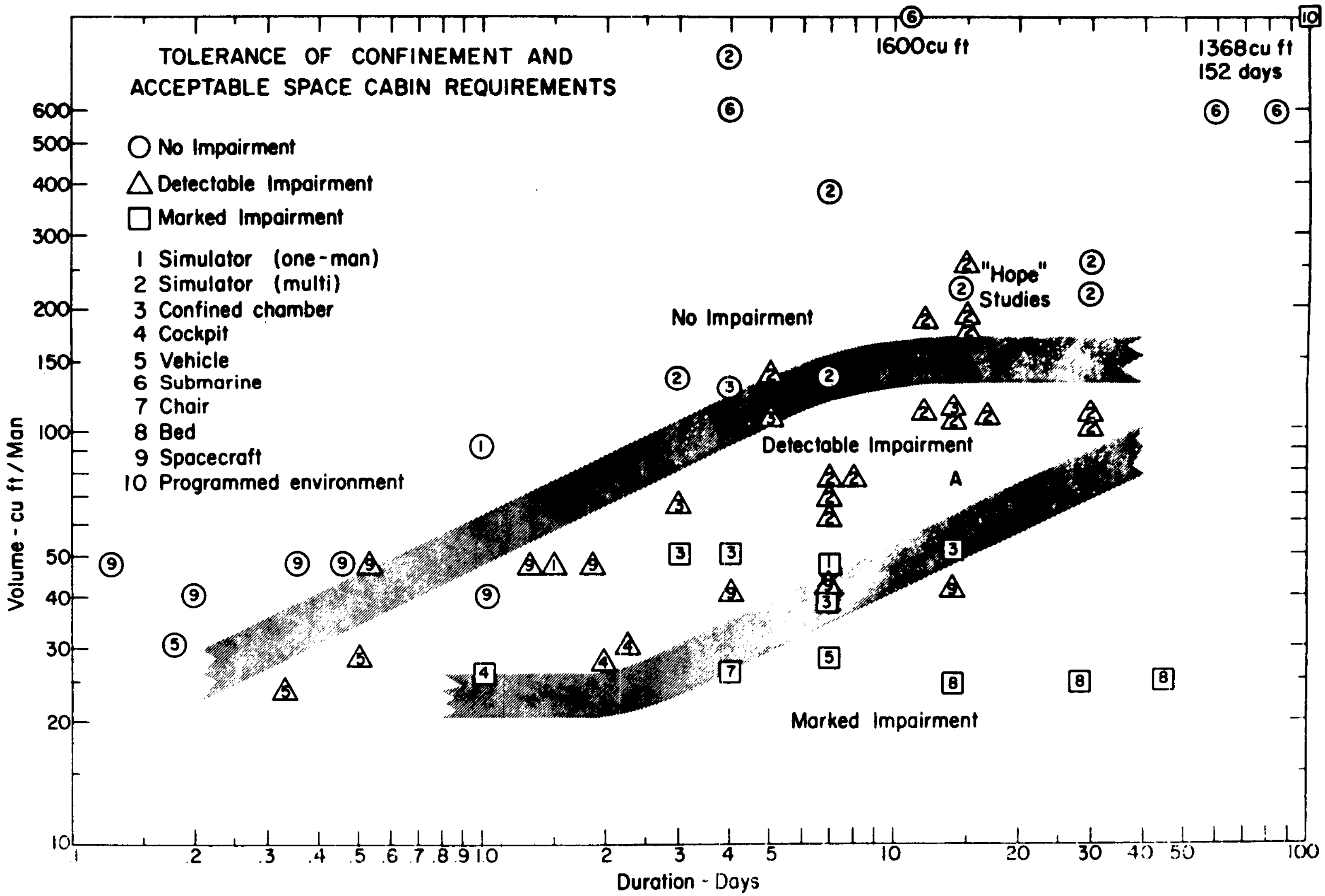


Reference 14

Preliminary requirements for crew volume versus space mission duration (Theoretical)

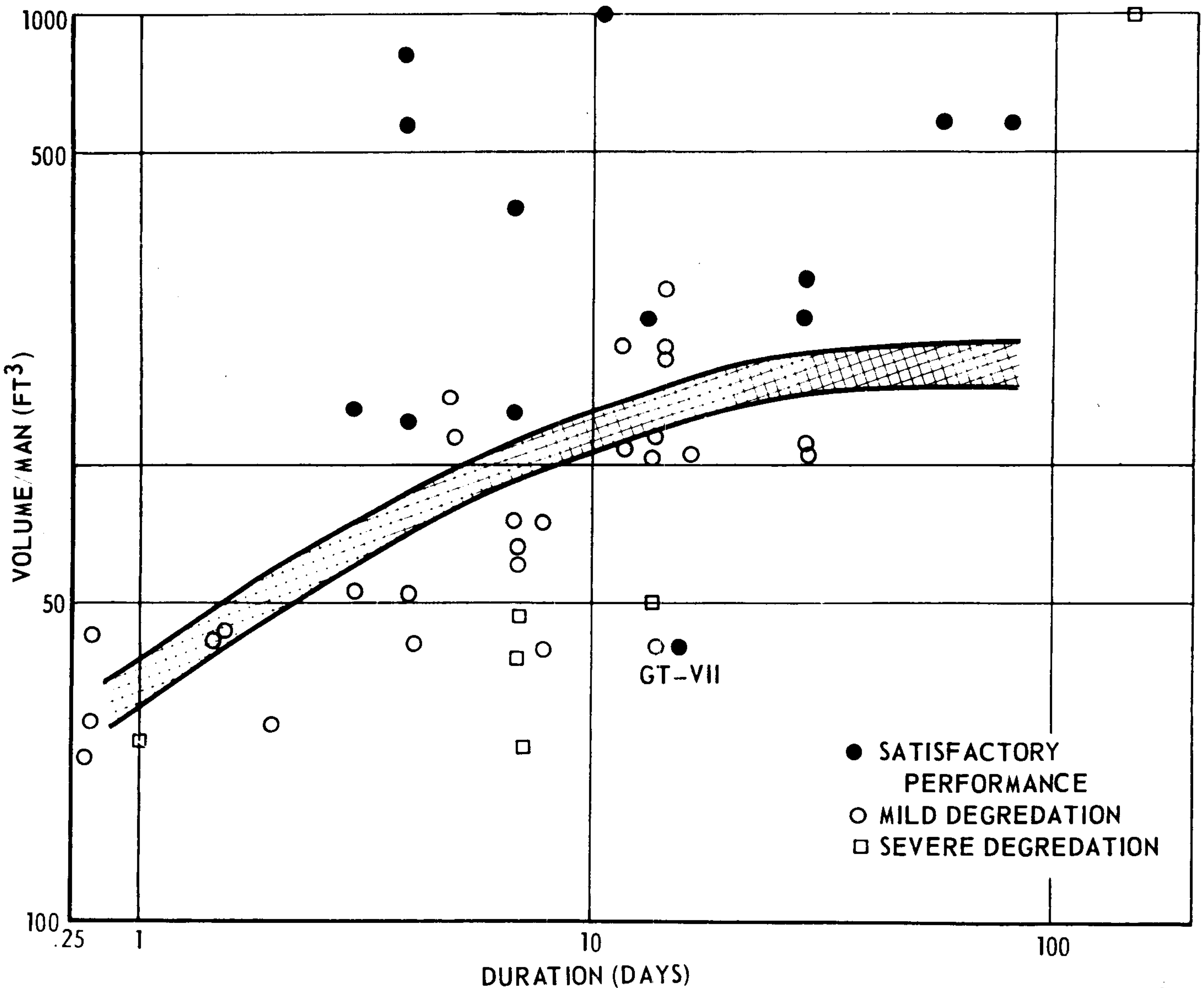
FIGURE 1



Reference 9

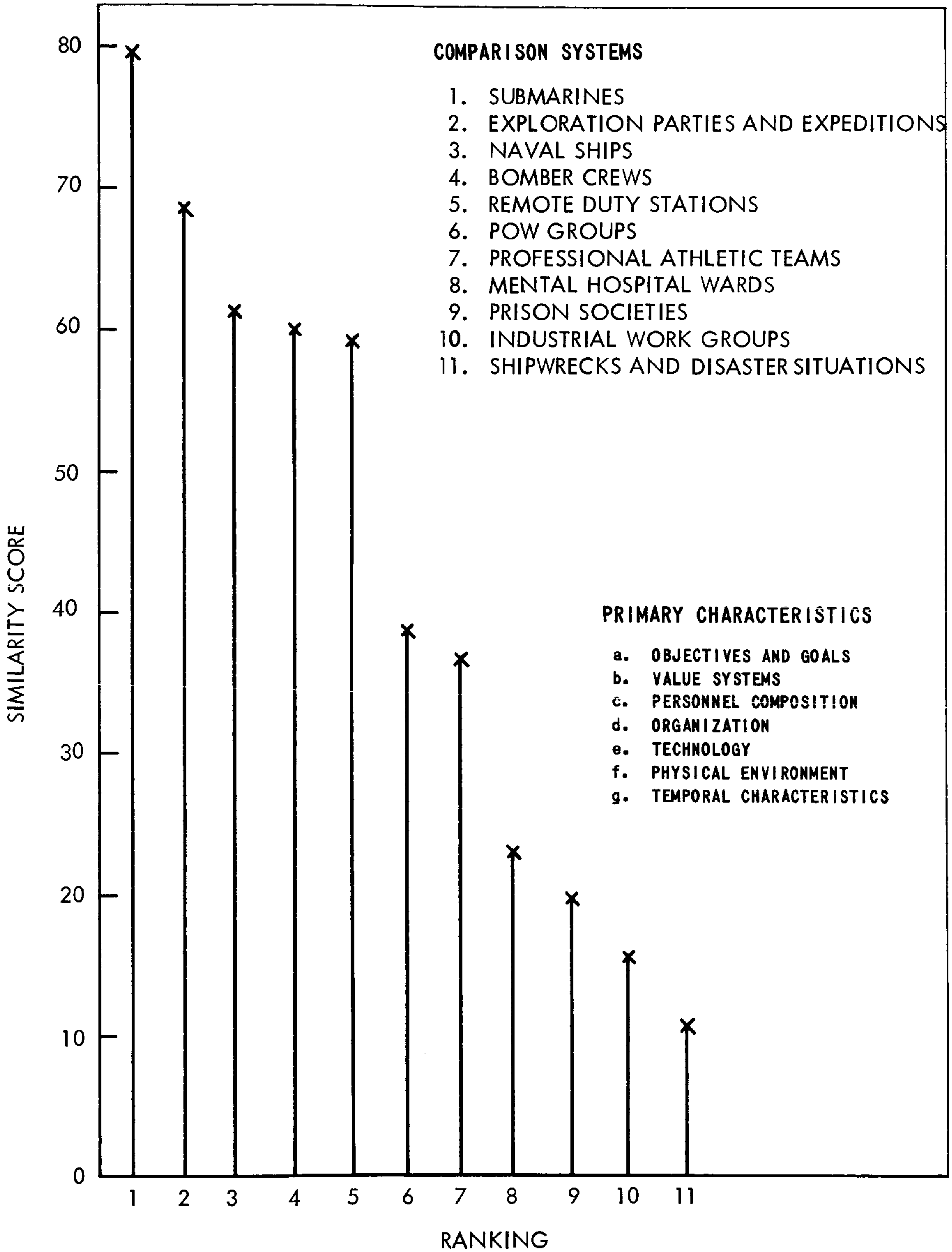
FIGURE 2

VOLUME PER MAN VS. MISSION DURATION UP TO 1966



Reference 16

FIGURE 3



SIMILARITY SCORES FOR ANALOG MISSIONS

DATA FROM REFERENCE 24

FIGURE 4

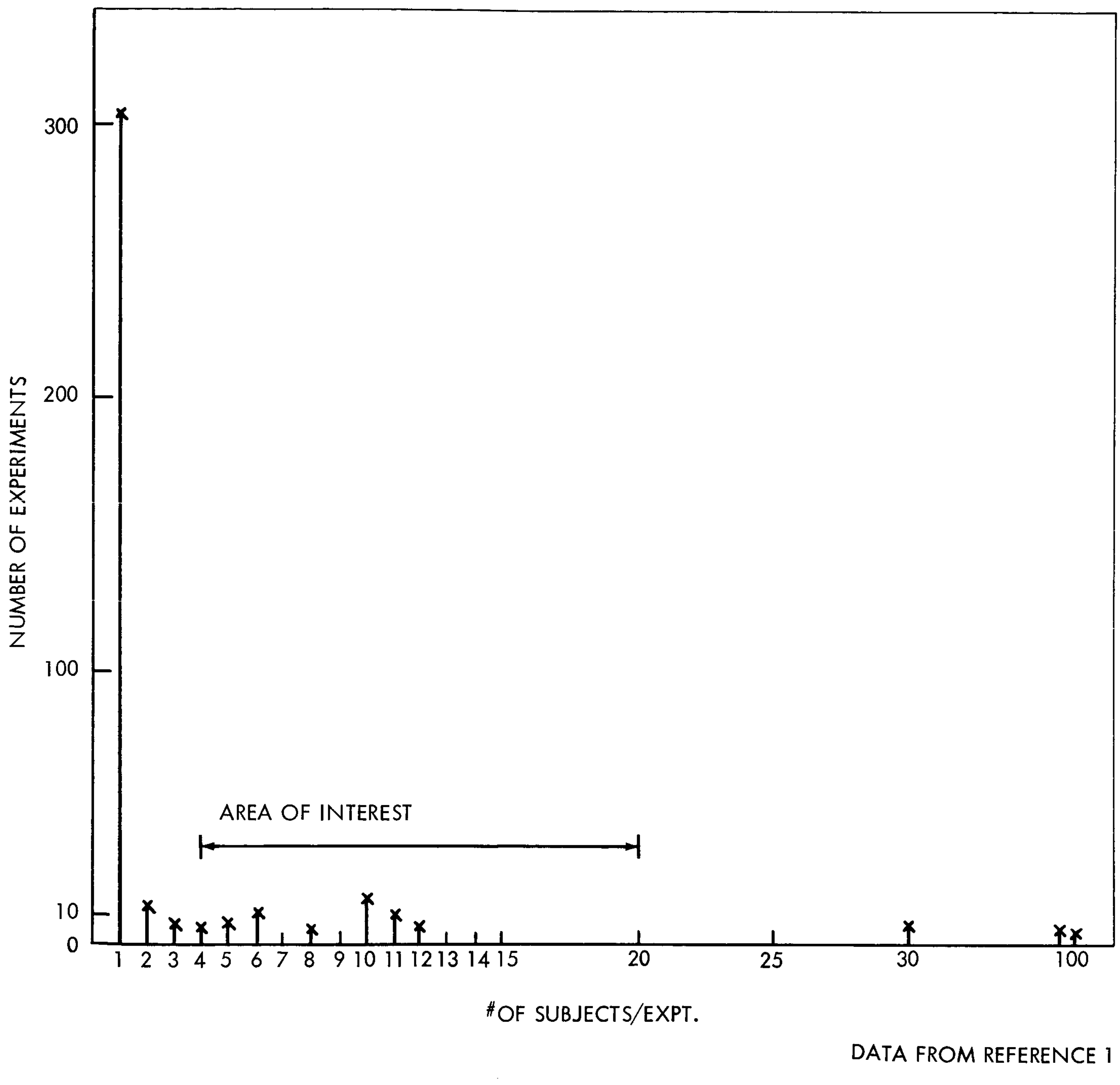
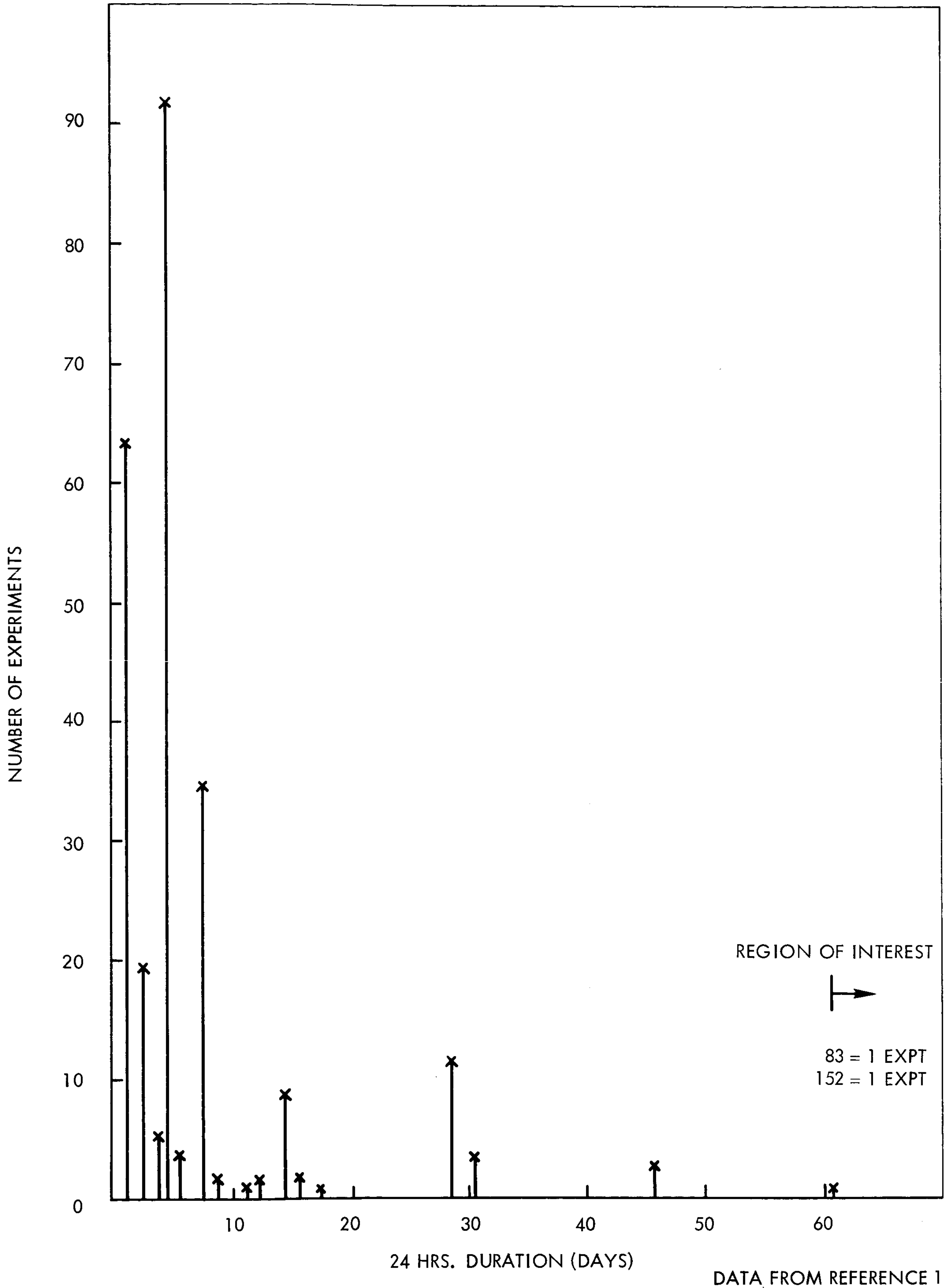

NUMBER OF EXPERIMENTS
300
200
100
10
0
AREA OF INTEREST
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 20 25 30 100
#OF SUBJECTS/EXPT.
DATA FROM REFERENCE 1

FIGURE 5



NUMBER OF EXPERIMENTS
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
24 HRS. DURATION (DAYS)
REGION OF INTEREST
83 = 1 EXPT
152 = 1 EXPT
DATA FROM REFERENCE 1

FIGURE 6